

said intermediate phase includes an average aluminum concentration in the range of about 18 to about 28% by weight, an average platinum concentration in the range of about 8 to about 45% by weight, and an average nickel concentration in the range of about 50 to about 60% by weight

so as to be non-stoichiometric relative to intermetallic compounds of aluminum and nickel, or aluminum and platinum, said outer layer region being substantially free of phase constituents other than said intermediate phase,

an alumina layer on the aluminide layer, and

a ceramic thermal barrier layer on the alumina layer.

22. The article of claim 21, wherein said intermediate phase resides in a beta solid solution intermediate phase region of a binary nickel-aluminum phase diagram.

23. The article of claim 21 wherein said outer layer region is about 1.5 to about 4.0 mils in thickness.

24. The article of claim 21 wherein said ceramic thermal barrier layer comprises a columnar microstructure.

25. The article of claim 21 wherein the ceramic thermal barrier layer comprises yttria stabilized zirconia.

26. An article for use in a gas turbine engine, comprising:

a nickel base superalloy substrate,

a chemical vapor deposited, diffusion aluminide layer formed on the substrate,

said aluminide layer having an outer layer region comprising a nickel-aluminum solid solution intermediate beta phase and an inner diffusion zone region proximate the substrate,

said intermediate phase including an average aluminum concentration in the range of about 18 to about 28% by weight, an average platinum concentration in the range of about 8 to about 45% by weight, and an average nickel concentration of about 50 to about 60% by weight so as to be non-stoichiometric relative to intermetallic compounds of aluminum and nickel and of aluminum and platinum, said outer layer region being free of phase constituents other than said intermediate beta phase,

a thermally grown alpha alumina layer on the aluminide layer, and
a ceramic thermal barrier layer vapor deposited on the alumina layer to have a columnar microstructure.

27. The article of claim 26 wherein said outer layer region is about 1.5 to about 4.0 mils in thickness.

28. The article of claim 26 wherein the ceramic thermal barrier layer comprises yttria stabilized zirconia.

29. A method of forming a thermal barrier coating on a substrate, comprising:
chemical vapor depositing a diffusion aluminide layer on the substrate which includes a nickel based superalloy substrate
under deposition conditions effective to provide an outer aluminide layer region comprising a solid solution intermediate phase and an inner diffusion zone region proximate the substrate,

said intermediate phase including an average aluminum concentration in the range of about 18 to about 28% by weight, an average platinum concentration in the range of about 8 to about 45% by weight, and an average nickel concentration of about 50 to about 60% by weight

so as to be non-stoichiometric relative to intermetallic compounds of aluminum and nickel, or aluminum and platinum, said outer layer region being substantially free of phase constituents other than said intermediate phase,

oxidizing the aluminide layer under temperature and oxygen partial pressure conditions effective to form an alpha alumina layer, and

depositing a ceramic thermal barrier layer on the alumina layer.

30. The method of claim 29 wherein said intermediate phase resides in a beta solid solution intermediate phase region of a binary nickel-aluminum phase diagram.

31. The method of claim 29 wherein said outer layer region is formed to a thickness of about 1.5 to about 4.0 mils.

32. The method of claim 29 wherein said ceramic thermal barrier layer is deposited by vapor condensation on said substrate so as to have a columnar microstructure.

33. The article of claim 21, wherein said intermediate phase comprises an average aluminum concentration of about 18 to about 27% by weight.

34. The article of claim 21, wherein said intermediate phase comprises an average aluminum concentration of about 18 to about 27% by weight, and an average platinum concentration of about 18 to about 45% by weight.

35. The article of claim 21, wherein said intermediate phase comprises an average aluminum concentration of about 21 to about 26% by weight and an average platinum concentration of about 30 to about 45% by weight.

36. The article of claim 21 wherein said outer layer region is about 2.5 mils in thickness.

37. The article of claim 21, wherein said intermediate phase comprises a surface, distant from said inner diffusion zone region, and the intermediate phase includes an average aluminum concentration and an average platinum concentration which is relatively high adjacent to the surface and decreases with increasing depth into the intermediate phase.

38. The article of claim 21, wherein said ceramic thermal barrier layer is deposited by electron beam physical vapor deposition.

39. The article of claim 26 wherein said intermediate phase comprises an average aluminum concentration of about 18 to about 27% by weight, and an average platinum concentration of about 18 to about 45% by weight.

40. The article of claim 26 wherein said intermediate phase comprises an average aluminum concentration of about 21 to about 26% by weight and an average platinum concentration of about 30 to about 45% by weight.

41. The article of claim 26 wherein said outer layer region is about 2.5 mils in thickness.

42. The article of claim 26 wherein said intermediate phase comprises a surface, distant from said inner diffusion zone region, and the intermediate phase includes the aluminum content and the platinum content which is relatively high

adjacent to the surface and decreases with increasing depth into the intermediate phase.

43. The article of claim 26, wherein said ceramic thermal barrier layer is deposited by electron beam physical vapor deposition.

44. The method of claim 29 wherein said intermediate phase comprises an average aluminum concentration of about 18 to about 27% by weight and, an average platinum concentration of about 18 to about 45% by weight.

45. The method of claim 29 wherein said intermediate phase comprises average aluminum content of about 21 to about 26% by weight and average platinum content of about 30 to about 45% by weight.

46. The method of claim 29 wherein said outer layer region is about 2.5 mils in thickness.

47. The method of claim 29 wherein said intermediate phase comprises a surface, distant from said inner diffusion zone region, and the intermediate phase includes the aluminum content and the platinum content which is relatively high adjacent to the surface and decreases with increasing depth into the intermediate phase.

48. The method of claim 29 wherein said ceramic thermal barrier layer is deposited by electron beam physical vapor deposition.

49. An article for use in a gas turbine engine, comprising:
a nickel based superalloy substrate,
a chemical vapor deposited, diffusion aluminide layer formed on the substrate,

said diffusion aluminide layer including an average aluminum concentration in the range of about 18 to about 28% by weight, an average platinum concentration in the range of about 8 to about 45% by weight, and a ceramic thermal barrier layer on the aluminide layer.

50. The article of claim 49 wherein said outer layer region is about 1.5 to about 4.0 mils in thickness.

51. The article of claim 49 wherein the ceramic thermal barrier layer comprises yttria stabilized zirconia.

52. An article for use in a gas turbine engine, comprising:
a nickel base superalloy substrate,
a chemical vapor deposited, diffusion aluminide layer formed on the substrate,
said diffusion aluminide layer including an average aluminum concentration in the range of about 18 to about 28% by weight, an average platinum concentration in the range of about 8 to about 45% by weight, and
a ceramic thermal barrier layer vapor deposited on the aluminide layer.

53. The article of claim 52 wherein said diffusion aluminide layer includes an average platinum concentration of about 18 to about 45% by weight.

54. The article of claim 52 wherein said diffusion aluminide layer is about 1.5 to 4.0 mils in thickness.

55. The article of claim 52 wherein the ceramic thermal barrier layer comprises yttria stabilized zirconia.

56. A method of forming a thermal barrier coating on a substrate, comprising:

chemical vapor depositing a diffusion aluminide layer on the substrate which includes a nickel based superalloy substrate,

said aluminide layer including an average aluminum concentration in the range of about 18 to about 28% by weight, an average platinum concentration in the range of about 8 to about 45% by weight, and

depositing a ceramic thermal barrier layer on the aluminide layer.

57. The method of claim 56 wherein said aluminide layer includes an average platinum concentration in the range of about 18 to about 45% by weight.

58. The method of claim 56 wherein said aluminide layer is formed to a thickness of about 1.5 to about 4.0 mils.

59. The method of claim 56 wherein said ceramic thermal barrier layer is deposited by vapor condensation on said substrate so as to have a columnar microstructure.

60. The article of claim 49, wherein said diffusion aluminide layer comprises an average aluminum concentration of about 18 to about 27% by weight, and an average platinum concentration of about 18 to about 45% by weight.

61. The article of claim 49, wherein said diffusion aluminide layer comprises average aluminum content of about 21 to about 26% by weight and average platinum content of about 30 to about 45% by weight.

62. The article of claim 49 wherein said outer layer region is about 2.5 mils in thickness.

63. The article of claim 49, wherein said diffusion aluminide layer comprises a surface, and the aluminum content and the platinum content is relatively high adjacent

to the surface and decreases with increasing depth into the diffusion aluminide layer and the substrate.

64. The article of claim 49, wherein said ceramic thermal barrier layer is deposited by electron beam physical vapor deposition.

65. The article of claim 52 wherein said diffusion aluminide layer comprises an average aluminum concentration of about 18 to about 24% by weight, and an average platinum concentration of about 18 to about 45% by weight.

66. The article of claim 52 wherein said diffusion aluminide layer comprises an average aluminum content of about 21 to about 26% by weight and an average platinum content of about 30 to about 45% by weight.

67. The article of claim 52 wherein the diffusion aluminide layer is about 2.5 mils in thickness.

68. The article of claim 52 wherein said diffusion aluminide layer comprises a surface, and the aluminum content and the platinum content is relatively high adjacent to the surface and decreases with increasing depth into the diffusion aluminide layer and the substrate.

69. The article of claim 52, wherein said ceramic thermal barrier layer is deposited by electron beam physical vapor deposition.

70. The method of claim 56 wherein said diffusion aluminide layer comprises an average aluminum concentration of about 18 to about 27% by weight, and an average platinum concentration of about 18 to about 45% by weight.

71. The method of claim 56 wherein said diffusion aluminide layer comprises average aluminum content of about 21 to about 26% by weight and average platinum content of about 30 to about 45% by weight.

72. The method of claim 56 wherein said diffusion aluminide layer is about 2.5 mils in thickness.

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73. The method of claim 56 wherein said diffusion aluminide layer comprises a surface, and includes the aluminum content and the platinum content which is relatively high adjacent to the surface and decreases with increasing depth into the diffusion aluminide layer and the substrate.

74. The method of claim 56 wherein said ceramic thermal barrier layer is deposited by electron beam physical vapor deposition.

75. An article comprising:
a nickel-base superalloy substrate including a substrate surface;
a single phase platinum-aluminide surface region proximate to the substrate surface, said article exhibiting an environmental life expressed in hours of exposure per 1 mil of the surface region of more than about 2 relative lives under high-velocity, 0.5 ppm salt environment at 2150°F.

76. The article of claim 75, wherein said aluminide surface region comprises from about 18 to about 28% by weight integrated aluminum content, from about 6 to about 45% by weight integrated platinum content and from about 25 to about 76% by weight integrated nickel content.

77. The article of claim 75 wherein said platinum-aluminide surface region has a thickness of from about 0.0015 to about 0.004 inches.

78. The article of claim 75, wherein said platinum-aluminide surface region comprises from about 20 to about 27% by weight integrated aluminum content and from about 18 to about 45% by weight integrated platinum content.

79. The article of claim 75, wherein said platinum-aluminide surface region comprises about 25 to about 62% by weight integrated nickel content.

80. The article of claim 75, wherein said platinum-aluminide surface region comprises about 21 to about 26% by weight integrated aluminum content and about 30 to about 45% by weight of integrated platinum content.

81. The article of claim 75, wherein said platinum-aluminide surface region comprises from about 21 to about 26% by weight integrated aluminum content and about 30 to about 34% by weight integrated platinum content.

82. The article of claim 75, wherein said platinum-aluminide region comprises from about 26 to about 49% by weight integrated nickel content.

83. The article of claim 75, wherein said platinum-aluminide region comprises from about 37 to about 49% by weight integrated nickel content.

84. The article of claim 75 further comprising a ceramic layer adjacent said substrate surface.

85. The article of claim 84 wherein the ceramic layer comprises yttria-stabilized zirconia.

86. The article of claim 75 wherein said platinum-aluminide surface region extends from the substrate surface into the substrate to a distance where the aluminum content is less than about 18% by weight.

87. The article of claim 75 wherein said nickel-base superalloy substrate is substantially a single crystal in form.

88. The article of claim 75 wherein said nickel-base superalloy substrate is RN5 or RN6.

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89. A method of forming a platinum-aluminide surface region proximate to the surface of a nickel-base superalloy substrate, comprising:

forming a platinum layer at the substrate surface by a method selected from the group consisting of electroplating, sputtering and metallo-organic chemical vapor deposition;

heating the substrate to a temperature of from about 1800 to about 2000°F for a time of about 2 hours;

depositing aluminum onto the nickel-base superalloy substrate by using an aluminum source and diffusing said aluminum into the substrate surface at an elevated temperature, at an aluminum activity of from about 40 to about 50 atomic percent in a pure nickel foil, and for a time of from about 4 to about 16 hours to form a substantially single phase platinum-aluminide surface region proximate the substrate surface, said platinum-aluminide surface region comprising from about 18% to about 28% by weight integrated aluminum content, from about 8 to about 45% by weight integrated platinum content and from about 31% by weight to about 74% by weight integrated nickel content.

90. The method of claim 89 wherein the heating of the substrate diffuses the platinum into the substrate.

91. The method of claim 89 wherein the aluminum is deposited at a temperature of about 1925 to about 2050°F.

92. The method of claim 89 further comprising the steps of annealing the platinum-aluminide surface region at a temperature of from about 1800 to about 2000°F for a time of from about 0.25 to about 2 hours.

93. The method of claim 92 further comprising the step of depositing a ceramic on the substrate surface.

94. The method of claim 93 wherein said ceramic includes yttria-stabilized zirconia.

95. An article comprising a single phase platinum-aluminide surface region proximate the surface of a nickel base superalloy substrate made by the method of claim 90.

96. An article comprising: a substrate which includes a nickel base superalloy; a diffusion aluminide layer comprising a substantially single phase, said single phase comprising an average aluminum concentration in the range of from about 18 to about 28% by weight, an average platinum concentration in the range of from about 8 to about 45% by weight, and an average nickel concentration in the range of from about 21 to about 74% by weight.

97. The article of claim 96 wherein said diffusion aluminide layer phase extends from the substrate surface into the substrate to a distance where the aluminum content is about 18% by weight or less.

98. The article of claim 96 wherein said nickel superalloy substrate is substantially a single crystal in form.

99. The article of claim 96 wherein said nickel superalloy substrate is RN5 or RN6.

100. An article having a platinum-aluminide surface region, comprising:
a substrate having a nickel-base superalloy substrate bulk composition and a substrate surface; and
a surface region at the substrate surface and extending from the substrate surface into the substrate to a distance defined by an upper limit of integration that is the distance where a weight percent of aluminum has decreased to 18% from a higher value closer to the surface, the surface region having an integrated aluminum content of from about 18 to about 28% by weight and an integrated platinum content of from about 18 to about 45% by weight, balance components of the substrate bulk composition, wherein the sum of the integrated aluminum content, the integrated platinum content, and the components of the substrate bulk composition in the surface region total 100% by weight.

101. The article of claim 1, wherein the integrated aluminum content of the surface region is from about 21 to about 23% by weight and the integrated platinum content of the surface region is from about 30 to about 45% by weight.

102. The article of claim 1, further including a ceramic layer overlying the surface region.

103. The article of claim 3, wherein the ceramic layer has a thickness of from about 0.005 to about 0.015 inches.

104. The article of claim 1, wherein the thickness of the surface region is from about 0.0015 to about 0.0004 inches.

105. The article of claim 1, wherein the substrate is selected from the group consisting of a turbine blade and a turbine vane.

106. The article of claim 1, wherein the nickel-base superalloy substrate is substantially a single crystal and the substrate bulk composition includes from about 6 to about 41 weight percent aluminum and from about 1 to about 8 weight percent rhenium.

107. The article of claim 1, where the nickel-base superalloy substrate is substantially a single crystal and the substrate bulk composition is selected from the group having a composition, in weight percent, consisting of (a) 7.5% cobalt, 7% chromium, 6.2% aluminum, 6.5% tantalum, 5% tungsten, 1.5% molybdenum, 3% rhenium, balance nickel; (b) 12.5% cobalt, 4.5% chromium, 6% aluminum, 7.5% tantalum, 5.8% tungsten, 1.1% molybdenum, 5.4% rhenium, 0.15% hafnium, balance nickel; and (c) 12% cobalt, 6.8% chromium, 6.2% aluminum, 6.4% tantalum, 4.9% tungsten, 1.5% molybdenum, 2.8% rhenium, 1.5% hafnium, balance nickel.

108. An article prepared by the method comprising the steps of:
providing a substrate having a nickel-base alloy substrate bulk composition and a substrate surface;

depositing a layer of platinum upon the substrate surface;
diffusing platinum from the layer of platinum into the substrate surface;
providing a source of aluminum, and
diffusing aluminum from the source of aluminum into the substrate surface for a time sufficient to produce a surface region at the substrate surface and extending from the substrate surface to a distance defined by an upper limit of integration that

is the distance where the weight percent of aluminum has decreased to 18% from a higher value closer to the surface, the surface region having an integrated aluminum content of from about 18 to about 28% by weight and an integrated platinum content of from about 18 to about 45% by weight, balance components of the substrate bulk composition.

109. The article of claim 15, further including a ceramic layer overlying the surface region.

110. An article prepared by a method comprising the steps of providing a substrate having a nickel-base superalloy substance bulk composition and a substrate surface; thereafter

depositing a layer of platinum about 0.0003 inches thick upon the substrate surface; thereafter

heating the substrate and layer of platinum to a temperature of about 1800-2000°F for a time of about 2 hours; thereafter

providing a source of aluminum in contact with the substrate surface, the source of aluminum having an activity of about 40 to about 50 atomic percent as measured in a pure nickel foil; and simultaneously

heating the substrate surface and source of aluminum to a temperature of about 1925-2050°F for a time of from about 4 to about 16 hours.

111. The article of claim 20, wherein the method of preparing the article includes an additional step, after the step of heating the substrate surface and source of aluminum, of